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On the Hydrogen-ion Concentration in the Alimentary Canal of Certain Orthopteroid Insects

By U. S. Srivastava & P. D. Srivastava

Department of Zoology, University of Allahabad, India

Introduction

There is little doubt that the hydrogen-ion concentration of the different parts of the alimentary canal is strongly related to their digestive activity and determines to a greater or lesser extent the mode of enzymatic action. There is, however, considerable divergence of opinion regarding the relationship between the hydrogen-ion concentration and the feeding habits of insects. It has been observed by some workers that within the same group different insects with different feeding habits show considerable difference with regard to the hydrogen-ion concentration in the midgut. Thus, Shinoda (1930) noted that the midgut is alkaline in the wood-eating beetles but weakly acidic in predacious ones, and Grayson (1955) has recently concluded that the pH reaction in the alimentary canal of Diptera is more closely related to the type of food consumed than with taxonomic relationship. At the same time, there are a number of observations that indicate a considerable degree of uniformity of pH in the midgut of different members of the same group, irrespective of the difference in the type of food and Waterhouse (1949) has inferred that the pH in the midgut of insects is independent of the type of the food eaten. This obviously indicates the presence of some common factor in the group which determines the midgut pH in the forms belonging to it.

With a view to clear these and other related controversies, the authors have undertaken the study of the pH of different parts of the alimentary

DOI: 10.21248/contrib.entomol.6.5-6.493-498

canal of several members of different groups. In the present paper, they have dealt with the pH of different parts of the gut of fifteen species of orthopteroid insects with varying feeding habits. Among other considerations, this group has been chosen first as the information regarding the pH of its members is rather meagre.

Table 1. Material and Technique

The insects examined together with their feeding habits are given in table 1.

S. No.	Name of insect	Family	Feeding habit
1.	*Gryllodes sigillatus (Walk.)*	*Gryllidae*	Omnivorous, saprophagous.
2.	*Gryllodes domesticus Linn.*	,,	Phytophagous, polyphagous, leaf eating.
3.	*Gryllotalpa africana Beauv.*	*Gryllotalpidae*	Phytophagous, oligophagous, stem eating and phytosaprophagous.
4.	*Brachytrypes portensosus Licht.*	*Gryllidae*	Phytophagous, leaf eating.
5.	*Schizodactylus monstrosus Dryry*	*Schizodactylidae*	Phytophagous, oligophagous, root eating.
6.	*Euconocephalus incertus Walk.*	*Tettigoniidae*	Phytophagous, polyphagous, leaf eating.
7.	*Aiolopus affinis Fab.*	*Acridiidae*	Polyphagous
8.	*Acrida exaltata Linn.*	,,	,,
9.	*Crotogonus* sp.	,,	,,
10.	*Atractomorpha crenulata Fab.*	,,	,,
11.	*Hieroglyphus nigrorepletus Bol.*	,,	Phytophagous, oligophagous, leaf eating.
12.	*Hieroglyphus banian Fab.*	,,	,,
13.	*Periplaneta americana Linn.*	*Blattidae*	Omnivorous, saprophagous
14.	*Phyllodromia germanica Linn.*	,,	,, ,,
15.	*Mantis religiosa Linn.*	*Mantidae*	Predacious, insect eating.

To determine the pH of the different parts of the gut, pH indicator paper[1]) method was used. The insects were starved for 4 to 8 hours to clear the alimentary canal of its contents to a considerable extent and then dissected in their own haemolymph. The entire alimentary canal was removed and spread over a clean slide. Parts of the gut were then separated, their food contents removed and the pH determined. The method of feeding insects with the indicators did not succeed, as in many cases the insects refused to feed upon these. Five trials were taken in each case and the average recorded.

Observations

In the case of each insect, the pH of the salivary glands, pharynx, oesophagus, crop, gizzard, intestinal caecae, mesenteron, hind intestine and rectum was noted. Besides the pH of the blood and faeces was also determined by bringing the indicator paper directly in contact with these.

The results obtained are given in Table 2.

[1]) Merck.

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It will be noted that, as a whole, the range of pH in the gut of the insects examined is fairly small, varying between 5.4 to 7 only, thus being more or less neutral and tending slightly towards acidity but not alkalinity at all. The salivary gland secretion in the different species examined is always slightly acidic, the minimum pH being 5.4 and the maximum 6.2. In the foregut, the pH range in the different species is 5.4 to 6.6; in the midgut it is 6.0 to 6.8 and in the hindgut 5.7 to 7.0 (although it is 7.0 only in one case viz. *Brachytrypes*). The range of pH of the blood is, likewise, 6.2 to 6.8 and of the faeces 5.8 to 6.8. Notwithstanding the exceptions, therefore, it can be stated generally that in these insects the midgut gives more neutral reaction than either the foregut or the hindgut which tend to be slightly acidic. In the words of Swingle (1931a), the hydrogen-ion concentration in these insects also, "increases from the mouth through the foregut and the midgut and decreases from the posterior part of the midgut through the hindgut".

It will also be noted that the pH of the midgut relatively shows a correspondence with the pH of the blood in each case.

Discussion

Based on the observation of the pH of the gut of forty species of insects representing seven orders, SWINGLE (1931a) concluded that in the majority of insects the alimentary canal is slightly acidic. He also stated that the pH increases from the foregut to the midgut and then again decreases in the hindgut.

Among the seven species of *Orthoptera*, examined by him, the foregut was acidic in all, the hindgut in five and the midgut in only two. In the remaining five species, the midgut was weakly alkaline, ranging between 7.18 to 7.55. In *Coleoptera*, the midgut showed a pH range of 5.5 to 9.5, although a pH above 7.0 was rather uncommon in this order. In the *Lepidoptera*, the midgut was distinctly alkaline, its pH ranging between 8.0 to 9.5. In the Hymenoptera, the pH of midgut ranged between 6.48 to 7.28. BODINE's record (1925) of seventeen species of *Orthoptera* also establishes the acidity of the alimentary canal but it does not show a definite rise and fall of pH in the midgut and hindgut as noted by Swingle. JAMESON & ATKINS (1921) have found the gut of *Bombyx mori* (*Lepidoptera*) to be alkaline. On the basis of the previous data and his own observations, WATERHOUSE (1949) concluded that, except the three butterflies of the family *Satyridae* examined by him, all the rest had „quite alkaline midgut", as in twentyeight out of the forty species of adults, the midgut pH was 8.4 or above and in the remaining twelve also the midguts were alkaline though rather weakly so. GRAYSON (1951), working on twenty insect species (10 adult grasshoppers, 1 adult cockroach, 8 lepidopterous larvae and 1 sawfly larva), has recorded the pH of stomach of grasshoppers to range between 6.4 to 6.7 and that of the lepidopterous larvae to range between 7.7 to 8.4. In the trichopteran

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Table 2

	Name of insect	Regions			
		Blood	Salivary gland	Pharynx	Oesophagus
1.	*Gryllodes sigillatus*	6.4—6.6	5.7—6.0	5.4	5.7—5.9
2.	*Gryllodes domesticus*	6.4—6.6	6.0—6.2	6.0	5.4—5.7
3.	*Gryllotalpa africana*	6.6—6.8	6.4	6.2	6.4
4.	*Brachytrypes portensosus*	6.2	5.7	6.2	6.2
5.	*Schizodactylus monstrosus*	6.2	6.2	6.2—6.4	5.4—5.7
6.	*Euconocephalus incertus*	6.6	6.0—6.2	6.2	6.0
7.	*Aiolopus affinis*	6.4	6.0	6.0	6.0
8.	*Acrida exaltata*	6.4—6.6	6.0	6.2	6.0
9.	*Crotogonus* sp.	6.6	5.8	6.2	6.0
10.	*Atractomorpha crenulata*	6.6	6.0	6.2	6.0
11.	*Hieroglyphus nigrorepletus*	6.6	5.8	6.0	6.0
12.	*Hieroglyphus banian*	6.6	6.0	6.0	6.2
13.	*Periplaneta americana*	6.8	6.0	6.0—6.2	6.0
14.	*Phyllodromia germanica*	6.4	6.0	6.2	6.2
15.	*Mantis religiosa*	6.2	5.4	5.4	5.8

midguts, SHINODA (1930) has noted the pH to range between 8.0 to 10.0. SHINODA (1930) and STAUDENMAYER (1940) have noted that the midgut of leaf eating or wood eating beetles is alkaline. SWINGLE (1931b) himself has also noted the pH of the midgut of Japanese beetle larvae to be approximately 9.5. The present observations on the pH in the orthopteran gut are essentially in agreement with those of earlier workers like BODINE, SWINGLE and GRAYSON showing that there is a considerable uniformity of pH within the group and the gut is weakly acidic to neutral in the majority of species. Nevertheless, it is also clear that in certain groups, e. g., the *Lepidoptera* and *Trichoptera*, alkalinity occurs not as a matter of exception but as a rule and, therefore, evidently SWINGLE's generalisation that the insect gut is slightly acidic does not hold good atleast for the midgut, the centre of enzymatic activity. But whether the pH in the insect guts as a whole shows a uniformity or not, within a certain group the midgut does show a remarkably small pH range. In other words, different groups of insects may differ from each other in respect of the range of pH in the midgut, some being clearly acidic, others alkaline and a large majority tending towards neutrality. It can, therefore, be stated safely that, while members within a certain group may vary from each other in respect to the pH of their midgut, the range of variation is determined by the group to which they belong.

The second part of SWINGLE's statement regarding the rise and fall of pH from the foregut to the hindgut through the midgut is, in fact, related atleast partly to the first one. Inspite of the controversy regarding the effect of the feeding habit of an insect upon the pH of different parts of the gut, it is more or less an accepted fact that at least the midgut pH remains fairly

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Crop	gizzard	Int. caecae	Mid-intestine	hind intestine	Rectum	Faeces
5.7—6.0	6.4—6.6	6.0	6.2—6.4	6.2—6.4	5.7	6.2
6.0—6.2	6.2	6.4	6.2—6.4	6.2	6.2	6.2
6.0—6.2	6.2	6.2	6.6	6.4	6.0—6.2	7.2
6.6	6.2	6.2	6.2	6.2	6.2	7.0
6.0—6.2	6.2	6.8	6.6—6.0	6.4	6.0	6.4
6.0—6.2	6.0—6.2	6.0	6.2	6.0	6.0	6.6
6.0	6.0—6.2	6.2	6.0	6.0—6.2	6.0	6.4
6.4	6.4	6.4	6.6	6.2	6.2	6.0
6.4	6.2	6.0	6.6	6.2	6.2	6.0
6.4	6.4	6.0	6.2	6.2—6.3	6.2—6.4	6.4
6.4	6.4	6.2	6.4—6.6	6.2	6.2	6.4
6.4	6.4	6.2	6.6—6.8	6.2	6.0	6.0
5.7—6.0	5.7—6.0	6.4	6.0—6.2	6.2	6.0	6.8
6.0	6.0	6.2	6.4	6.2	6.0	6.0
5.8	5.6—5.8	5.8	6.0	5.7	5.6—5.8	5.8

constant. Thus, in the case of an insect with neutral midgut, if the food is acidic, the pH tends to increase from the foregut to the midgut. On the other hand, if the pH of the food and hence of the foregut is higher, it tends to decrease in the midgut. Examples of this latter condition are the *Neuroptera*, certain beetles (like *Gyrinidae*, *Chauliognathus*, *Epicauta*, etc. (SWINGLE, 1931a). However, in the hindgut, the medium almost always tends to become acidic and the pH declines. In the *Orthoptera*, since the midgut is more or less neutral and the foregut very weakly acidic, this range of pH is not great.

BODINE (1925) has not established any correlation between the pH value of the gut and the type of food taken by an insect, nor has SWINGLE (1931a) done so. WIGGLESWORTH (1927) states that the hydrogen-ion concentration "is not a physiological constant for the animal" but that the concentration varies according to the type of food eaten. He has noted difference in the pH of exclusively protein fed and exclusively carbohydrate fed *Blatella germanica*, but even he has noted "relative constancy" in the midgut, the pH of stomach of protein fed and carbohydrate fed German cockroach being 6.4 and 6.3 respectively. By feeding *Popillia japonica* larvae on ninety two soil samples representing four different soil types with pH ranging from 3.0 to 6.9, SWINGLE (1931b) has come to the conclusion that the pH of different parts of the digestive tract of the larvae was not greatly influenced by the pH of the soil on which the larvae were fed. The average pH of the foregut ranges between 8.04 to 8,34, of the midgut 9.5 (approximately) and of the hindgut 7.72 to 7.97. In the *Orthoptera*, the hydrogen-ion concentration is fairly constant as the records of BODINE (1925), SWINGLE (1931a) and GRAYSON (1951) show. SHINODA (1930) and STAUDENMAYER (1940) have noted the midgut of leaf eating and wood eating Coleoptera to be alkaline and that of the

DOI: 10.21248/contrib.entomol.6.5-6.493-498

predacious ones to be weakly acidic. WATERHOUSE (1949), as a result of his study of the guts of adult *Lepidoptera* and of carnivorous lepidopterous larvae, has generalised that the midgut alkalinity is characteristic of Lepidoptera, whether it is a carnivorous larva or a nector feeding adult.

The bulk of evidence thus goes to show that the hydrogen-ion concentration in the midgut is more or less independent of the nature of food the insect may take, although insects with widely different feeding habits may have different pH.

Summary and conclusions

The hydrogen-ion concentration of the foregut, midgut and hindgut in the fifteen species of orthopteroid insects studied ranges from 5.4 to 6.6, 6.0 to 6.8 and 5.4 to 7.0 respectively.

The data at our disposal leads us to the following conclusions: —

(1) that different groups of insects may differ widely from each other in respect to the pH of the alimentary canal but within a group the range of variation is limited and determined by the group to which the insects belong;

(2) that, while insects with different feeding habits may show different midgut pH, the midgut pH of the same insect is not markedly affected by different food given to it, i. e., the midgut pH shows a 'constancy';

(3) that the pH in the foregut and the hindgut may show a variation with change of food; and

(4) that there exists a marked degree of correspondence between the pH of the midgut and that of the blood.

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DOI: 10.21248/contrib.entomol.6.5-6.493-498